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The Influence of Habitat Factors on Relative Abundance of Roe Deer *Capreolus pygargus* During the Summer in a Baekdudaegan Protected Area in South Korea

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H-SH conceived the ideas, conducted data analysis, contributed to writing the original paper, reviewed, and edited the final draft. HK performed the data analysis, visualized data, and reviewed. H-GC supported writing of the original paper and reviewed. NK supported the writing of the original paper and reviewed. H-CS conceived project administration and funding acquisition. HJK conceived project administration and funding acquisition. SJ reviewed, supported and edited the final draft.

Key words
Food resource, Habitat preference, Protected area, Relative abundance index, Roe Deer, Vegetation

ABSTRACT

Understanding the relationship between habitat variables and species-specific habitat preferences is crucial for effective species conservation and management. We investigated the effect of vegetation structure on the habitat preference of roe deer *Capreolus pygargus*. From April 2021 to December 2023, camera traps were deployed in the Baekdudaegan Protected Area in South Korea. Vegetation structure surveys were conducted annually from June to August between 2021 and 2023. Prior to the field surveys, we assessed the homogeneity of the survey area using K-means clustering. The relative abundance index (RAI) of roe deer was higher in areas with relatively higher elevation compared to those at lower elevations. Differences in roe deer RAI based on elevation levels were not due to habitat conditions but rather to differences in protective strength. Roe deer RAI was correlated with the coverage of arborescent vegetation and plant composition, coverage of deciduous trees between 1 m and 2 m above ground, and the presence of Poaceae and Liliaceae species under 1 m. In South Korea, Cervidae primarily feed on plants under 2 m in height. Therefore, shrub and grass coverage, which represent the availability of food resources for roe deer, correlated with their RAI. Moreover, the composition of vegetation in the habitat also influenced roe deer preferences, with less preference shown for certain food resources. Our study suggests that the quantity and availability of food resources are important factors influencing habitat preference in roe deer.

INTRODUCTION

The habitat preference of animals is influenced by the structural and functional dynamics of their environment, which are shaped by species-specific characteristics related to food resources, spatial use, life cycles, and behaviors (Rovero *et al*., 2014). Consequently, understanding species habitat preferences can provide valuable insights into their ecological traits (Son *et al*., 2017).

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The structure and composition of forest vegetation is closely related to the availability of nutrients and the quantity and quality of food resources consumed (Tremblay *et al*., 2007). Food resources within a habitat are primary factors influencing habitat preference among species. In South Korea, Cervidae, a family of herbivorous mammals, feed on herbs (including grasses), shrubs, and various tree species (Lee *et al*., 2022). Food preference varies according to habitat characteristics, including wetlands, mountainous regions, lowlands, coastal areas, and seasonal changes (Felton *et al*., 2018). Furthermore, vegetational structure affects survival rates by providing concealment from predators. Denser forests, which exhibit higher productivity, increase the availability of food resources and enhance sensory limitations for predators through more effective camouflage (Newman and D'Angelo, 2024). Consequently, numerous studies have demonstrated that dense forests offer abundant, high quality food resources and effective concealment from predators, making them preferred habitats for Cervidae

(Demarchi and Bunnell, 1993; Hemami *et al*., 2004; Wu *et al*., 2019).

Furthermore, species that utilize similar spatial and food resources may engage in competition due to resource limitations. This competition can exacerbate habitat degradation caused by fragmentation and destruction resulting from human activities. Increased competition necessitates greater energy expenditure for survival, which can lead to population growth exceeding the habitat's carrying capacity (Freedberg *et al*., 2021). Consequently, species may disperse to other habitats or adopt different spatial usage patterns based on their specific needs. In South Korea, four species of Cervidae have been recorded: the roe deer Capreolus pygargus, water deer *Hydropotes inermis*, red deer Cervus elaphus, and sika deer *Cervus nippon hortulorum* (Jo *et al*., 2018). However, red deer and sika deer are found only in the northern part of the Korean Peninsula, near Mt. Baekdu. Therefore, roe deer and water deer are the most common Cervid species in South Korea. Furthermore, the absence of large carnivores, such as the Siberian tiger *Panthera tigris tigris* and lynx *Lynx lynx* which have been locally extirpated has led to a continuous increase in the population size of roe deer and water deer (Eom *et al*., 2023). This population growth has resulted in several issues, including roadkill and agricultural damage.

Increasing the population of Cervidae in South Korea requires more effective management efforts. However, there is a lack of information regarding the habitat use of roe deer in South Korea. To implement effective management strategies, detailed knowledge of the ecology of roe deer is essential. Therefore, we examined habitat use patterns of roe deer focusing specifically on the effect of vegetational structure on their habitat preferences.

MATERIALS AND METHODS

Study area

This study was conducted during April 2021 to December 2023 in the Chunwangbong to Myojeckryong region (35º 15' - 36º 54' N, 127º 28' - 128º 28' E, 380 m – 1150 m) within the Baekdudaegan Protected Area in South Korea. This area has been protected since 2005. The spatial range of the study area exceeds 1,010 km² and encompasses various land types, including urban, agricultural, forested, grasslands, wetlands, and aquatic areas (Ministry of Environment, 2020). To minimize the impact of habitat variables on the roe deer population, we selected two types of areas based on the K-means clustering algorithm (Kurniawan and Fatulloh, 2017). Before calculating the K-means clustering algorithm, we assessed six variables: Distance from the watershed, landcover (Ministry of Environment, 2020), soil drainage level (Rural Development Administration, 2013), digital elevation model (DEM), slope, and aspect (Fig. 1). The DEM, slope, and aspect were derived from a digital topographic map (National Geographic Information Institute, 2020). The K-means clustering algorithm partitions the data into clusters, grouping data with similar characteristics into the same cluster while separating data with differing characteristics into other clusters. Following the application of the K-means clustering algorithm, we created a grid sized 3 km x 3 km to cover the study area. We assigned values to the grid based on the majority value from the K-means clustering results and selected 30 grids, dividing them into two types (Fig. 2). The six variables utilized in K-means clustering elevation, slope, aspect, distance from the watershed, land cover, and soil drainage level indicate that five of these variables, excluding elevation, do not differ between Area 1 and Area 2. Notably, Area 1 has a higher elevation than Area 2 (Table I).

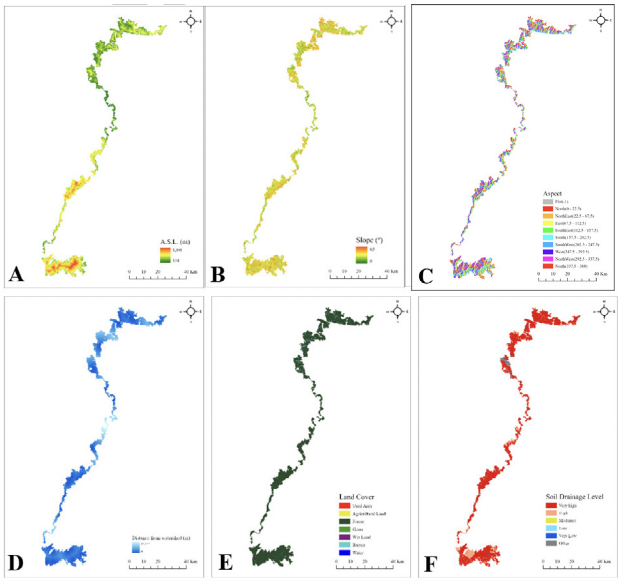

Fig. 1. Variables of calculating study area on Chunwangbong to Myojeckryong region in Backdudaegan protected area in South Korea for K-means clustering algorithm. (A) digital elevation model, (B) slope, (C) aspect, (D) distance from watershed, (E) landcover, (F) soil drainage level.

Relationship of vegetation coverage and roe deer abundance

We used vegetation and mammalian data collected from the ecological survey of Baekdudaegan Protected Area from 2021 to 2023. During the study period, 30 camera traps (Reconyx, HC600) were installed in the designated study area. Each camera trap was assigned a unique serial number and positioned 1 to 2 m above the ground. All camera traps operated continuously for

24 h a day over a total of 5219 days. In the temperate zone, the period from June to August features maximum vegetation coverage, providing sufficient food resources for roe deer. Consequently, to identify the relationship between vegetation coverage and roe deer abundance while avoiding confounding effects caused by behavioral changes due to starvation we focused exclusively on data collected from June to August each year. We defined an independent trap event as a situation in which the same species was recorded within a 30-min interval. If the same species was captured within 30 min, we considered it a single capture event. We identified independent capture events for roe deer and water deer, totaling 557 and 881 events, respectively. Subsequently, we calculated the relative abundance index (RAI) for every 100 days, as follows:

$$RAI = (A / N) \times 100$$

where A represents the total number of independent captures, and N denotes the number of trap days for a specific species.

During the June to August period, within 250 m from the camera trap, set up the 15 m x 15m grid. Vegetation structure was calculated in five categories: grass, shrub, arborescent, tree. And considered about height of two categories, could feed between 0 m to 2 m, consequently we calculated the proportion of coverage based on two (shrub): coniferous and deciduous, and four categories (grass (including herbs)): Poaceae, Fabaceae, Liliaceae, and Asteraceae (Table II). Moreover, coverage of vegetation was categorized 6: 0 (percentage coverage = under 1 %), 1 (1-5 %), 2 (6-25 %), 3 (26-50 %), 4 (51-75 %), and 5 (75-100%) (Westhoff and Van der Maarel, 1978).

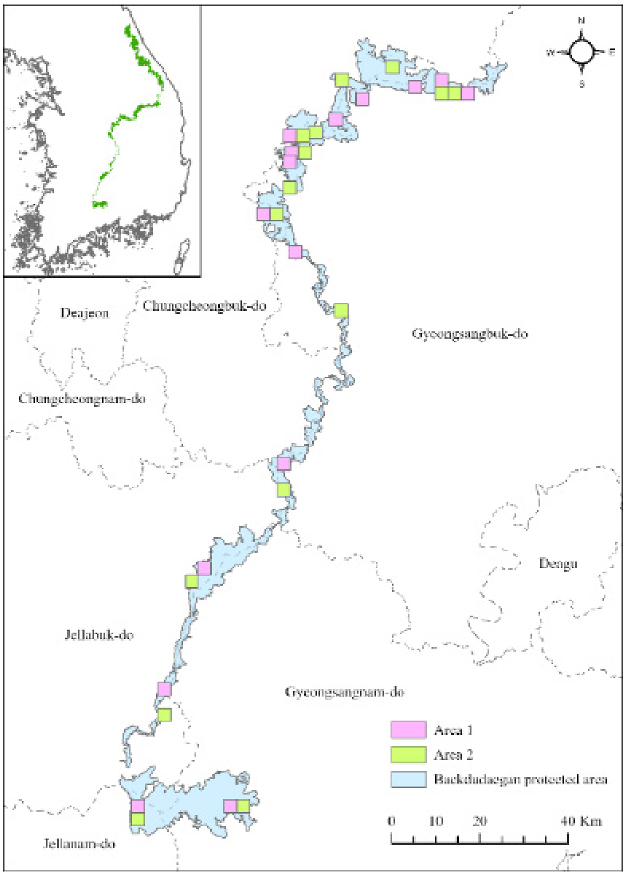

Fig. 2. Study area from calculated habitat homogeneity by K-means clustering algorithm on Chunwangbong to Myojeckryong region in Backdudaegan protected area in South Korea.

Table I. Characteristics of habitat variables (mean ± S.E.) between area 1 and area 2 on Chunwangbong to Myojeckryong region in Backdudeagan protected area in South Korea.

Variables	Area 1	Area 2	Z	p
A. S. L. (m)	728.01±47.90	600.34±39.80	4.20	<0.05
Slope (°)	21.09±0.53	19.29±0.71	4.14	0.05
Aspect (°)	178.12±0.74	179.27±1.10	0.75	0.40
Distance from watershed (m)	2077.37±211.33	2399.23±473.64	0.39	0.54
Landcover *	1.00±0.00	1.00±0.00	0.00	1.00
Soil drainage level**	5.00±0.00	5.00±0.00	0.00	1.00

*: Dominant landcover, 1: deciduous forest, 2: coniferous forest. **: 5: Very high, 4: High, 3: Moderate, 2: Low, 1: Very Low.

Table II. Differences of vegetation structure (mean ± S.E.) between area 1 and area 2 on water deer (*H. inermis*) and roe deer (*C. capreolus*) located Backdudeagan protected area, South Korea.

Variables	Area 1	Area 2	Z	p
Tree_cover	4.87±0.09	4.60±0.34	0.59	0.45
Arborescent_cover	1.40±0.16	1.33±0.16	0.09	0.77
Shrub_cover	2.20±0.14	2.53±0.22	1.65	0.21
Shrub_deciduous	4.73±0.15	4.27±0.36	1.44	0.24
Shrub_coniferous	0.07±0.07	0.13±0.09	0.35	0.56
Grass_cover	1.67±0.27	1.80±0.33	0.10	0.76
Grass_Poaceae	1.80±0.35	1.67±0.32	0.08	0.78
Grass_Fabaceae	0.07±0.07	0.13±0.13	0.20	0.66
Grass_Liliaceae	0.40±0.16	0.33±0.19	0.07	0.79
Grass_Asteraceae	1.00±0.20	0.33±0.16	7.00	0.01

Tree_cover, Coverage (%) of over 15m vegetation; Arborescent_cover, Coverage (%) of between 2m to 15m vegetation; Shurb_deciduous, Coverage (%) of between 1m to 2m deciduous; Shurb_coniferous, Coverage (%) of between 1m to 2m coniferous; Grass_Poaceae, Coverage (%) of under 1m Poacea; Grass_Fabaceae, Coverage (%) of under 1m Fabaceae; Grass_Liliaceae, Coverage (%) of under 1m Liliaceae; Grass_Asteraceae, Coverage (%) of under 1m Asteraceae.

To evaluate the influence of habitat variables on the RAI of roe deer and water deer, we performed a statistical analysis using R (ver. 4.4.1). We performed a Mann-Whitney U test to evaluate the differences in habitat factors and RAI across each study area. Additionally, to mitigate potential multicollinearity issues in the models, we calculated the variance inflation factors (VIF) for each influencing factor. The VIF for all factors was less than four, indicating no significant multicollinearity in the analysis. We employed a Generalized Linear Models (GLMs) to model the RAI of both roe deer and water deer in relation to landscape indices and vegetation structure. Following model selection based on AIC (ΔAIC < 2), we calculated the averaged regression coefficients and assessed the relative variable importance using the MuMIn R package (Bartoń, 2016).

RESULTS

During the study period, RAI of roe deer was higher in Area 1 than in Area 2 (Fig. 3). Vegetation structural variables did not differ significantly between Area 1 and Area 2, except for the coverage of Asteraceae. The coverage of Asteraceae was significantly higher in Area 1 than in Area 2 (Table II).

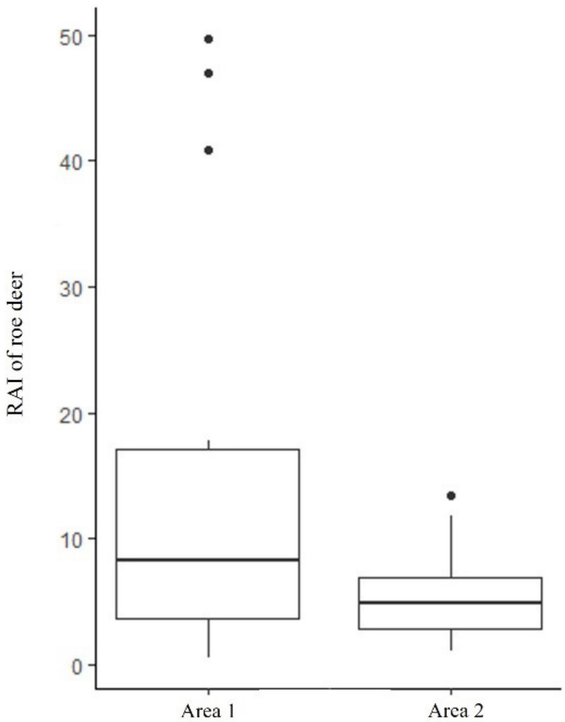

Fig. 3. Differences of relative abundance index (mean ± S.E.) between area 1 and area 2 on roe deer (*C. capreolus*) located Backdudeagan protected area, South Korea.

The plant food resources available to roe deer across the entire study site were predominantly composed of deciduous trees between 1 m and 2 m above the ground (Z = -11.50, $p < 0.01$). Additionally, Poaceae, the grass family, dominated the vegetation under 1 m in height (F = 11.48, $p < 0.01$) (Fig. 4).

The top-ranked model on the relative abundance index of roe deer was -0.12× Arborescent_cover + 0.05 × Shrub_deciduous -0.05 × Grass_Liliaceae (χ^2-test, p < 0.001). The second model on the relative abundance index of roe deer -0.13 × Arborescent_cover + 0.05 × Shrub_deciduous + 0.02× Grass_Poaceae – 0.05× Grass_Liliaceae (χ^2-test, p < 0.01) (Table III). For roe deer, the coverage of arborescent plants and Poaceae showed strong correlations with RAI. Specifically, arborescent plant coverage was negatively associated with the RAI of roe deer, whereas Poaceae coverage on the ground was positively associated with RAI. Additionally, the coverage of shrubs and Liliaceae on the ground was correlated with the RAI of roe deer (Table IV).

Table III. Coefficients and relative variable importance, including the models that explains the variability in the relative abundance index of vegetation variables for each species

Model	AIC_c	ΔAIC_c	ω	R^2
(Intercept + Arborescent_cover + Shrub_ deciduous + Grass_Liliaceae)	228.48	0.00	0.59	0.40
(Intercept + Arborescent_cover + Shrub_deciduous + Grass_Poaceae + Grass_Liliaceae)	230.08	1.60	0.27	0.43

Table IV. Models based on the correlated Akaike Information Criterion (AICc) developed to explain the relative abundance index (RAI) of Korean water deer (*H. inermis*) and roe deer (*C. capreolus*) in each vegetation structure ranked by the ΔAICc value resulted by the generalized linear model

Variables	Coefficient	S.E.	t	P	Relative variable importance
Intercept	0.04	0.10	0.37	0.73	
Arborescent_cover	-0.13	0.04	-3.60	0.00	1.00
Shrub_deciduous	0.05	0.02	2.40	0.03	0.00
Grass_Poaceae	0.02	0.02	1.17	0.25	0.68
Grass_Liliaceae	-0.05	0.03	-1.43	0.17	0.09

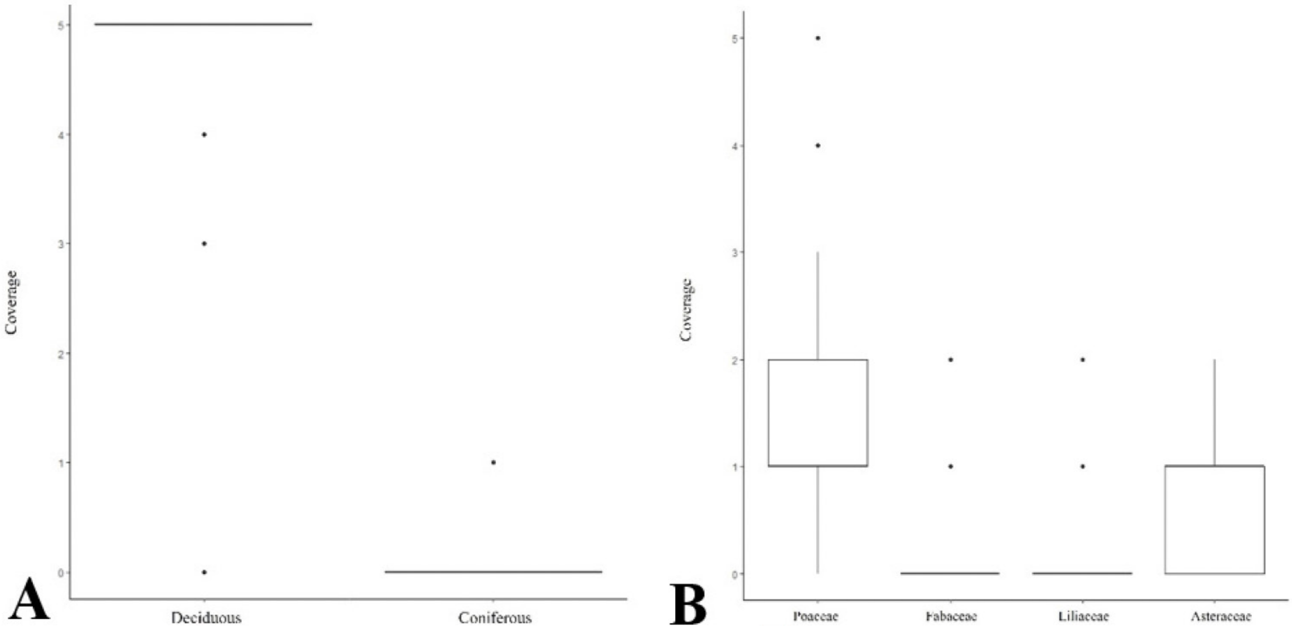

Fig. 4. Differences of composition of vegetations on (a) between 2 m to 1 m above ground, (b) under 1 m on study area located Backdudeagan protected area, South Korea.

DISCUSSION

On the Korean Peninsula, roe deer inhabits diverse environments, including forests, grasslands, agricultural lands, and urban areas. Roe deer prefers higher elevations, which are associated with lower temperatures that reduce thermoregulatory costs and alleviate heat stress (Pagon *et al*., 2013). However, the elevation difference between Area 1 and Area 2 in our study was approximately 100 m, which does not explain the observed differences in the RAI of roe deer. Elevation is strongly correlated with slope gradient (Iwahashi *et al*., 2001). Increasing slope gradient is associated with a higher probability of falling and greater climbing energy expenditure (Birn-Jeffery and Higham, 2014; Nations *et al*., 2019). Moreover, steeper slopes influence human activity by increasing economic costs and the risk of accidents (Chen *et al*., 2023). The Baekdudaegan protected area, which serves as our study site, is established along a mountain ridge with high elevation. Additionally, the higher-elevation zones within the study area are more strongly protected under the Baekdu-daegan Protection Act as core districts than lower area represented buffer districts. Consequently, areas at higher altitudes pose challenges for human activities such as road construction and crop harvesting (Geldmann *et al*., 2014; Chen *et al*., 2022), which may affect habitat selection by roe deer. Therefore, the RAI of roe deer differed between Area 1 and Area 2.

The structure of vegetation within a habitat is strongly correlated with the habitat use of Cervidae (Hwang *et al*., 2014). The coverage of the upper vegetation layer influences that of the lower layer by affecting the amount of solar energy and rainfall it receives (Eom *et al*., 2018). Generally, Cervidae species in South Korea prefer dense vegetation coverage below 2 meters, as it provides concealment from predators and access to food resources (Eom *et al*., 2018). Our results also indicate that roe deer is negatively influenced by arborescent coverage. Additionally, coverage of deciduous shrubs and Poaceae grasses positively affects roe deer. Arborescent coverage is negatively correlated with shrub and grass coverage, which serve as food resources and provide predator concealment. Therefore, in the GLMs for roe deer, variables related to arborescent coverage may have similar effects on habitat selection. Moreover, the composition of vegetation in ground and shrub layers can influence habitat selection (Freschi *et al*., 2022; Kim *et al*., 2011). In our study, the vegetation composition was dominated by deciduous species in the shrub layer and Poaceae in the grass layer. Food availability within the habitat is one of the most important factors influencing habitat preference (Moser *et al*., 2006). Furthermore, roe deer food preferences vary with environmental conditions and season, sometimes showing no clear preference or avoidance for specific food resources (Tixier *et al*., 2009). Therefore, in our study, the dominance of Poaceae in the grass layer and deciduous trees in the shrub layer likely influences roe deer by providing food resources during the summer.

Although our study focused on the short-term effects on roe deer habitat preference and was limited by data constraints that prevented estimation of population dynamics, it indicated that the quantity and availability of food resources are important factors influencing habitat preference of roe deer during the summer in our study area.

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Generative AI and AI-assisted technology statement

The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Statement of conflict of interest

The authors have declared no conflict of interest.

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